Preliminary Draft of Breakout Session Material Produced During the July 20-21, 2010 Deep Vadose Zone Technical Forum

The following preliminary draft material contains the knowledge and capability needs captured by the Breakout Session Chairs/Co-Chairs from participant discussions during the July 20-21, 2010 Deep Vadose Zone Technical Forum held in Richland, Washington. The order of topics covered is: (1) Characterization and Monitoring, (2) Subsurface Processes and Predictive Modeling, and (3) Subsurface Access and Remediation.

On July 21, the Chairs for each Breakout Session presented their draft information before all Forum participants and received feedback. The Chairs/Co-chairs will combine common elements between Sessions (e.g., characterization needs), add introductory material, and then repackage their findings into text files for use in the Deep Vadose Zone Program Plan.

July 27, 2010

Characterization and Monitoring

Breakout Session

Vadose Zone Characterization & Monitoring High Priorities

The following topics were identified as the three highest priority needs for deep vadose zone characterization and monitoring:

1. **Living Conceptual Models of a Vadose Zone System**
2. **Improved Vadose Zone Tools & Approaches**
3. **Toward Best Vadose Zone Characterization Practices**

These three topics are related to each other in that the conceptual model both guides and relies on the development of new tools and approaches, and experience with those methods at deep vadose zone sites will lead to best characterization practices.

The topics are also closely linked with priorities in the 'Processes and Predictive modeling' area, as characterization and mentioning is needed to parameterize and validate models (respectively), and all characterization, modeling and monitoring are all required for process understanding.

The topics are also closely linked with priorities in the 'Remediation Technologies and Approaches' area, as characterization is needed to guide treatment design and monitoring is needed to validate treatment success.

The following slides describe these three topics…..

Characterization & Monitoring Priority # 1

Living Conceptual Models of a Vadose Zone System: A site conceptual model is a description of the system's characteristics and dynamics: it usually includes an interpretation of how the contamination was released into the subsurface and the hydrogeological and (bio)geochemical processes that influence contaminant migration and remediation. Ideally, site conceptual models are 'living' in that they are developed in an iterative manner. Early conceptualizations, which are often based on theoretical understandings and sparse site-specific data, are used to guide data acquisition and experimentation. Insights from these investigations are in turn used to refine the conceptual model, and so on.

The group ranked this as a key priority to emphasize that there is no single sensor or measurement that will allow us to develop an understanding of the system behavior with the confidence needed to parameterize reactive transport models or guide remediation treatment design. Instead, a sustained and iterative approach is needed to identify the key components that most influence overall system behavior and responses to remediation treatments. Some examples of data and approaches that should be considered in the development of a living conceptual model are described below.

- Develop initial conceptual model of site using:
  - Existing data about physical system (log, geological information, historical etc..)
  - Historical and current records/data associated with the nature and extent of contamination
  - Theoretical understanding of system
  - Analogue site data.
- Perform iterative characterization and experimentation to identify components that most influence contaminant transport and remediation efficacy in the vadose zone, potentially including:
  - 3D architecture of subsurface (thin/fine layers and geological discontinuities); moisture and metric potential; permeability and associated spatial correlations; gas, aqueous, and solid phase geochemical variabilities and gradients; microbial abundance, diversity, and potential for reactivation.
- Improved development of proxy (petrophysical, pedotransfer) relationships
  - For linking (for example) well log responses with grain size or surface geophysical responses with moisture, lithofacies and saline
- Develop routine methods for integrating a variety of (direct and proxies) datasets to enable tractable characterization and monitoring over field relevant scales.

Characterization & Monitoring Priority #2

Improved Vadose Zone Tools & Approaches. Several tools and approaches that would generally be helpful for identifying key controls on contaminant fate and transport in a vadose zone environments were identified; many of these are listed below. As a site conceptual model is developed and site-specific controls on contaminant behavior are identified, additional approaches will likely be needed to characterize and monitor those controls over field-scales.

- Screening tools for identifying contaminant distribution
- Tools for documenting source migration pathways (isotopic ratios and laser approaches for soil gas isotopic analysis)
- Pore fluid characterization approaches that provide information about speciation and form of complexes in low moisture environments;
- Sensors/methods for monitoring flux (moisture, specific contaminants, gas)
- Advanced sensors/methods for characterizing moisture, permeability, porosity (NMR, pneumatic crosshole)
- Improved downhole tools/logs to identify species of particular radioactive contaminants (Tc 99, I129)
- Quantification of mineralogy and mechanisms (FTIR, vadose zone reactive gas tracers)
- Methods for monitoring distribution of injected remediation treatment and induced transformations in-situ and over field-relevant scales (pH, isotopes, time-lapse geophysics)

Characterization & Monitoring Priority #3

Toward Best Deep Vadose Zone Characterization Practices. Several practices were identified that would facilitate current as well as future vadose zone investigations. Examples include:

- Overcoming site sampling/drilling/completion standards, including:
  - Routine implementation of downhole log suites (neutron, density)
  - Evaluate alternatives to standard Hanford well practices (that use non-stainless steel casings) and consider alternative installation procedures
  - Use dedicated geophysical holes to permit better contact of sensors and formation and improved time-lapse imaging.
- Developing standard sampling and implementation protocols
  - For soil gas indicators, geophysics, and other vadose zone characterization methods
- Dedicated efforts to coordinate, leverage, and transfer from a DVZ Central Plateau Applied Research Site with…
  - other Hanford contaminated vadose zone sites that could benefit from or leverage with the Research Site activities;
  - other key DOE investments at instrumented test sites (INEL vadose zone research park, Hanford 300 area, etc) to permit improved understanding of vadose zone processes relevant to contaminant migration and remediation in a variety of hydrogeological settings.
- Develop a centralized data management system
  - that uses an accepted protocol for archiving and documenting hydrological, biological, geochemical, geophysical, and other subsurface data relevant to contaminant fate and transport

Break Out Group Discussions

The following slides document some of the comments associated with the following 5 categories. These comments were used to develop the three priority characterization and monitoring research challenges that were described on previous slides.

- **Characterization**
  2. Nature and Extent of Source
  3. Subsurface Properties: key controls on vadose zone flow and transport (hydro-bio-geochemical)
- **Monitoring** of Contaminants and system response to treatment
  4. Contamination and moisture
  5. Remediation Efficacy (near and longer term)

1. Cross Cutting Observations / Recommendations

1. Observations/Cross Cutting Approaches

Crosscutting Approaches:

- Improved methods are needed to integrate different datasets as needed to provide vadose zone characterization/monitoring data over field-relevant scales. Capitalize on:
  - Information from: direct and indirect (proxies); expensive and cheap; integrative and point measurements
  - Can employ estimation procedures (geostatistical/Bayesian), coupled modeling, or joint inversion for improved understanding of controlling properties and processes.
- Exploit coupled heterogeneity during characterization and monitoring.
  - For example, sediment geochemistry is often coupled to physical heterogeneity, and moisture/texture/microbial abundance are often coupled in the vadose zone. Establishing these relationships can reduce the number of samples needed to capture variability of a variety of vadose zone properties.
- Adopt of a strategy of opportunistic sampling when interrogating/manipulating DVZ
- Nested and iterative model driven experimentation and observation is needed.
  - A single new tool or method employed at a single scale will not provide enough information about the vadose zone to guide sustainable remediation.

Observations:

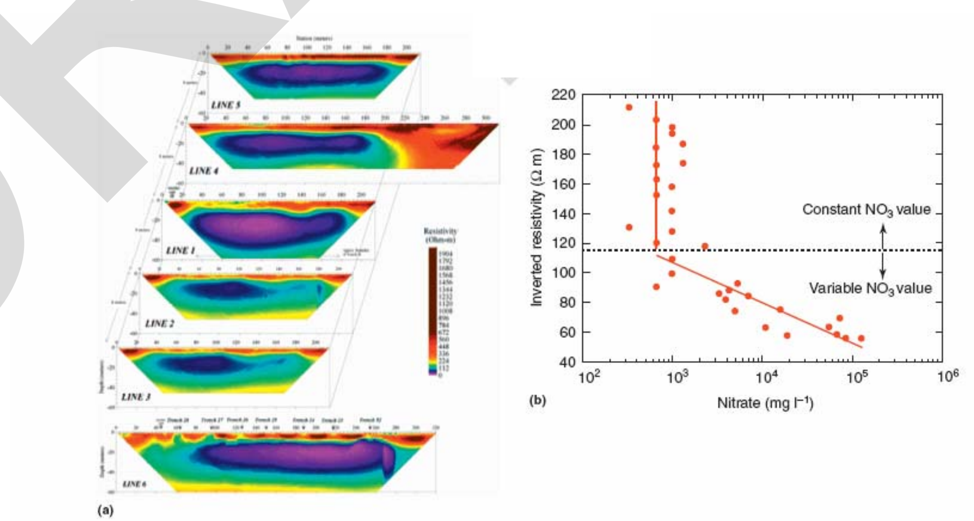
- Ways to account for uncertainty, assess alternative conceptual models (properties, mechanisms), and document 'minimal but sufficient' characterization are needed.
- Enhance central database: Leverage on Hanford environmental information system (HEIS), EM DOEGLE effort, ASCEM data management (etc) efforts to develop a common approach for archiving and documenting hydrological, biological, geochemical, geophysical, and other subsurface data.
- Concerted effort to coordinate with, leverage on, and transfer advancements developed at DVZ to other DOE sites of interest:
  - Many other contaminated vadose zone sites exist at Hanford outside of the Central Plateau (i.e., 100D) - can communication lines be established so that the DVZ tools and expertise will be a resource for other sites?
  - Other (instrumented) vadose zone sites exist (INEL vadose zone site, 300, etc) – can we develop a DVZ Applied Field Study Site plan that is aligned or leverages with activities at other sites?
  - Tc, U are high priorities in Hanford VZ. Will Hanford-based DVZ applied field study center yield insights, technologies and methodologies that are relevant other vadose zone contaminated sites (i.e., Pu)?
- Characterization at Hanford could be improved through overcoming site (or standard) wellbore practices:
  - Routine implementation of suites of downhole logs (neutron density)
  - Evaluate alternatives to standard well practice that use non-stainless steel casings, alternative installation procedures
  - Dedicated geophysical holes (not multi-use) to permit better electrical contact (direct push with gyros?)

2. Key DVZ Characterization Need: Nature and Extent of Source

Methods are needed to characterize the contaminant source speciation, phase, and concentration as well as its history and current distribution. Examples include:

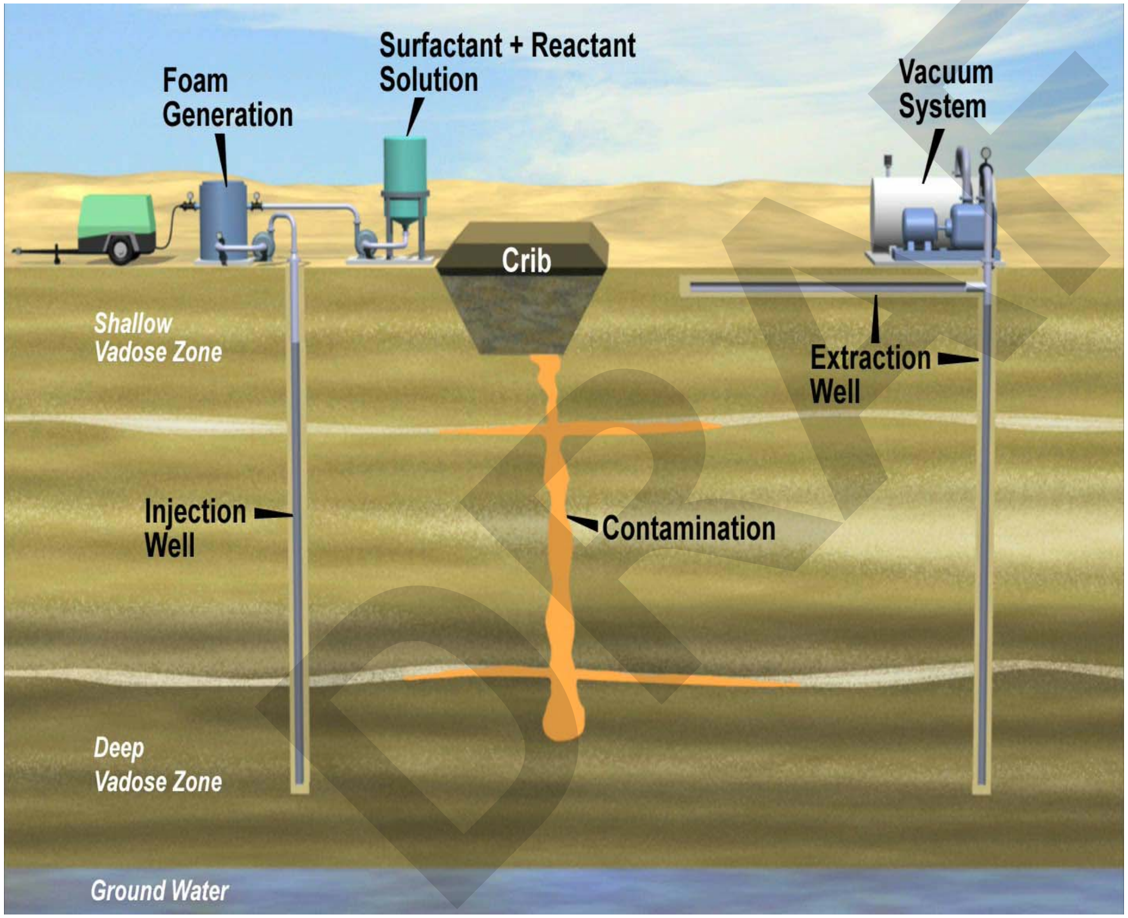
- A retrospective analysis of historical records (including logging records and water flux from process history) should be a standard procedure.
- Improved downhole tools/logs to identify species of radioactive contaminants (Tc 99, I129)
- Improved isotopic fingerprinting of source using isotopic ratios and laser approaches for soil gas isotopic analysis
- Screening tools, including use of proxies (Electrical conductivity for high TDS; Moisture/texture; moisture for texture and microbial abundance, etc.)

Hanford Central plateau delineation of nitrate plume using surface electrical methods (modified from Rucker and Fink, 2007)



DVZ SYSTEM PROPERTIES

Characterizing the key (hydrological, geochemical, microbiological) in the deep vadose zone



These properties:

1. Control contaminant and moisture migration;
2. Influence success of remediation treatment;
3. Are needed to parameterize reactive transport models.

DVZ SYSTEM PROPERTIES

What are the key controls on contaminant fate, transport, and remediation efficacy in the vadose zone?

1. Physical

- 3D subsurface architecture, especially key facies interfaces, fine grained layers, geological discontinuities
  - direct push, geophysics, other
- moisture/perched zones -
  - Geophysics conditioned to logs, NMR, other
- Permeability, permeability anisotropy, and hydrogeological property spatial correlation. Use of:
  - Analogue sites
  - Facies-based information
  - Proxies (moisture for texture, etc.)
  - Crosshole pneumatic tests
- Borehole low moisture matrix potential

2. Geochemical

Aqueous - better techniques are needed for pore fluid characterization that provide info about form/phase of complexes and colloids in low moisture environments.

Solid phase –Better techniques are needed for characterization of host mineral phases in deep vadose zone and spatial distribution of sorption models.

•Reactive tracers, novel FTIR logs, in-situ core studies.

Gas Phase –Methods are needed for rapid field soil gas sampling and analysis, where the samples can be used to directly to:

•characterize the contaminant

•Infer information about contaminants, mechanisms (O_2, He, CO_2~redox; radon~natural U: soil gas phase indicators).

3. Microbial

Microbial - abundance, diversity, mobility, and potential for reactivation as function of moisture/nutrients.

3. MONITORING:

CONTAMINANTS and MOISTURE flux

- Sensitive/selective moisture/contaminant flux approaches/tools for low moisture environment
- Matrix potential changes
- DTS fiber optics - temp/moisture connections.
- time-lapse geophysical imaging
- Microbial community indicators

4. REMEDIATION MONITORING:

NEAR TERM:

•Methods needed to monitor the distribution of injected treatment or carrier (i.e., reactive gas or foam) over space and time

•Methods needed to monitor the (bio)geochemical transformations that are induced through the remediation treatment, including localized transformations and the formation of reaction fronts and gradients. *Methods to inform if we are we inducing the desired reactions and if they are sustainable.*

- •pH
- •Identification of end-process indicators (direct or indirect)
- •Improved pore fluid samples that provide sufficient volume and are representative of in-situ environmental conditions.
- •time-lapse geophysics (complex resistivity for tracking in-situ solid phase transformations)
- •Isotopic indicators of induced reactions
- •Validation/screening level sampling – multi-level sorbant pads, DTS, Sea Mist
- •Microbial community indicators
- •Key indicators of unintended consequences

LONGER TERM MONITORING:

•Automated measurement suites that work in high TDS and low moisture (temperature and others)

•Sensitive early warning indicators (direct and indirect)

Subsurface Processes and Predictive Modeling Breakout Session

Key Research Needs

1. Develop models for reactive flow and transport coupled processes in the DVZ
2. Data assimilation and conceptual model analysis of historical plumes in the DVZ
3. Analyze long-term system-scale response to water flow through the DVZ
4. Resolve technical issues associated with reactive gas and foam delivery in the DVZ
5. Crosscutting for all above research elements: Uncertainty Quantification in the DVZ

Develop models for reactive flow and transport coupled processes in the DVZ

- How are the pore water and gas geochemistry different in the DVZ?
- Is microbiology different in the DVZ and will it affect contaminant behavior and remediation efficacy?
- What is the geochemical reactivity of phases in the DVZ, including close to equilibrium behavior?
- What are the inter-grain geometries and behaviors in the DVZ?
- What are the spatial auto- and cross-correlation structures? What is correlation between hydrologic and geochemical parameters/processes.

Data assimilation and conceptual model analysis of historical plumes in the DVZ

- Analyze historical data for consistency in plume behavior
  - Recharge, lateral spreading, fast vertical flow paths, perched water
- Using risk and cost/benefit to determine need for additional data and level of uncertainty that is acceptable
- Use history matching for model testing

Analyze long-term system-scale response to water flow through the DVZ

- Flow and transport under very dry conditions and/or in gravel (film flow potentially important)
- Impacts of widely differing ionic strength on unsaturated flow (osmotically driven water flow)
- Long term 3D response to water addition, experimentation with characterization at relevant scales
- Influence of antecedent moisture conditions on preferential flow and related geochemical effects
- Behavior of transition between unsaturated and saturated zone over time

Resolve technical issues associated with reactive gas and foam delivery in the DVZ

- Reactive gas and foam (non-Newtonian fluid) delivery and reactivity in the DVZ
- Characterization and modeling across multiple scales to understand multi-scale geochemical and flow dynamics of remediation techniques
- Program likely to consist of a combination of laboratory, and shallow and deep field experiments

Uncertainty Quantification in the DVZ

- Crosscutting to all of the research elements: Development and application of methodology for UQ at a DVZ site
  - Uncertainty due to data scarcity and measurement and interpretation errors
  - Parameter estimation error
  - Conceptual model (assumptions) uncertainty
  - Scenario uncertainty
  - Error propagation through models

Subsurface Access and Remediation Breakout Session

Subsurface Access and Remediation

Ultimate Goal is Remediation of Vadose Zone. To achieve this goal, invest in:

Measures of Success & Long-Term Effectiveness – high, short-term

1. Document(s) that provides a baseline evaluation of cost and expected effectiveness of possible technologies – high, near-term
2. Technologies and methods for determining endpoints and risk appropriate for DVZ treatment to support RI/FS – high, near-term
3. New practical monitoring methods for the vadose zone – high, mid-term
4. New, site and scenario specific leach tests – high, mid-term
5. Methodologies that use multiple lines of evidence – high, near-term

Pilot Scale Testing – high, short-term

1. Test sites in different locations/strata – high, near-term
2. Test sites in clean areas for equipment/strategy testing prior to testing in contaminated area– med, near-term
3. Multi-use sites: single test site for multiple technologies – high, near-term

Improved access & delivery methods – high, short-term

1. Practical new tools and strategies for subsurface access, characterization, and monitoring (e.g., transfer tools developed for cone penetrometer or conventional drilling) – high, near-term
2. Remediation focused characterization techniques – high, near-term
3. On-line, near real-time information repository accessible to many, containing field data, results, etc. (like Triad approach) – mid-term, med
4. Improved or new technologies (e.g., hydraulic hammer direct push, cable-tool for shallow, and combinations of access methods; gases, foams, shear thinning fluids for delivery) – high, near-term
5. Practical methods to sequester Tc and uranium independent of redox - high, near-term

6. Determination of the depth effectiveness of surface/near surface barriers (e.g., engineered covers, injection grouting) – high, near-term

7. Combinations of multiple ("defense-in-depth") remedial strategies – med, mid-term

Knowledge Management – high

1. Technology Readiness Assessment and Tracking (e.g., CLU-IN for vadose zone) – short-term, EM-32, high

2. Identification and development of remediation scenarios to provide a platform for evaluating remediation, characterization, and monitoring technologies – high, short-term

3. Reinstituting the Technology Coordination Group (TCG) – med, mid-term

4. Digitizing existing and new information from within and outside site so more user-friendly, accessible. Ensure that knowledge is preserved during contractor transitions and change-overs. Information should include technology challenges and limitations – high, mid-term

5. Core Lab for archiving samples, specifically rad samples. Preservation is needed for non-rad, rad, and biological samples for future experiments/analyses. Must have someone take responsibility for maintaining the library for at least 3 generations to go from now through remediation through monitoring – high, mid-term